1907–2007: What's new on the Blazhko front?

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1907-2007: What's new on the Blazhko front?

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Abstract. On the centenary of the discovery of the Blazhko effect [1], it is time to give a rundown of what progress has been made over the past decade in the understanding of the phenomenon. The Blazhko effect is a periodic amplitude and/or phase modulation of the light curve, shown by a large fraction of the astrophysically important RR Lyrae stars. Despite numerous devoted observational studies and elaborate models attempting to reproduce the modulation, it still defies a definitive explanation. This paper attempts to give an overview of the observational and theoretical status of studies devoted to the phenomenon.

1. RR Lyrae stars and the Blazhko effect

The astrophysical importance of the RR Lyrae stars is undisputable [2]. These pulsating variables have periods of 0.2-1.2 day, and show brightness variations of the order of a magnitude. Until not so long ago, they were considered to be prototypes of radially pulsating stars.

The most intriguing subclass of RR Lyrae stars consists of stars showing the Blazhko effect, the phenomenon of amplitude or phase modulation, which was named after one of its discoverers [1]. The light curves of Blazhko stars are modulated on time scales ranging from a few days up to hundreds of days. Fig. 1 shows the modulation for RR Lyrae, the prototype of the class and one of the best studied Blazhko stars. For this star, the pulsation period is 13h36min and the Blazhko period was about 39 days at the time the observations were made (see also [3]). The estimated incidence rate of Blazhko variables among the galactic RRab stars (fundamental mode pulsators) is about 20-30%. [4,5] For the RRc Blazhko stars (first overtone pulsators) this rate is less than 5%. In the LMC the incidence rate for RRab stars is only half as large [6,7]. The recent discovery of low modulation amplitudes [8,9] leads us to suspect the incidence rate of the Blazhko effect may be even higher.

The Blazhko effect has been the frequent subject of photographic and photometric studies ([10], and references therein). Since the phenomenon was traditionally studied from photometric data by means of O-C analysis, the observations were in general strongly biased towards the ascending branch and maximum phase of the primary light curve, a poor sampling method for Fourier analyses. Nevertheless, some photometric data sets, which also include other parts of the light curve, allow a rigorous frequency analysis (e.g. [11-13]). Systematic studies of accurate CCD data of globular clusters (e.g., MACHO, OGLE) have cast a new light upon the study of RR Lyrae variability [5-7], and have yielded important statistics on the phenomenology of the Blazhko effect. In recent years important new results have been obtained for short-period Blazhko stars at Konkoly Observatory, Budapest, Hungary, with the newly refurbished

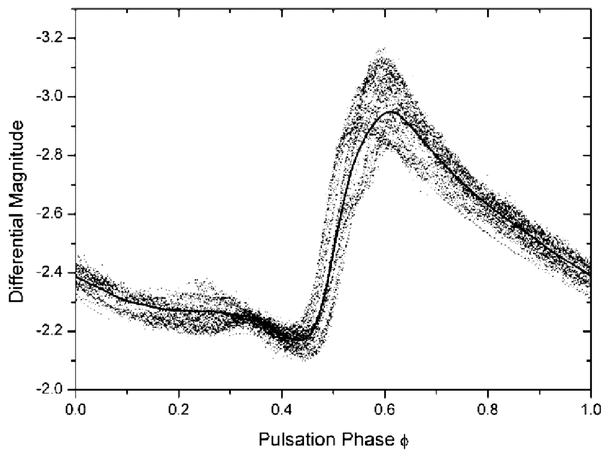

Figure 1. The light curve changes at different phases in RR Lyrae 's Blazhko cycle. Based on photometric data gathered in 2004 [3].

automatic 60-cm telescope, resulting in the first multicolour photometric millimag studies with a complete coverage over both pulsation and Blazhko cycle, e.g. [8,9]. Most spectroscopic studies devoted to the Blazhko effect in RR Lyrae stars were devoted to the brightest Blazhko star, RR Lyrae ($m_V(\max) = 7.2$ mag [13-19]. Other Blazhko stars all have visual magnitudes beyond $m_V(\max) \simeq 9$ mag, and only recently detailed spectroscopic studies of these fainter stars have become possible.

2. Properties of Blazhko stars

As a typical defining feature resulting from the light curve modulation, the frequency spectra of light curves of RR Lyrae Blazhko stars exhibit either a doublet or an equally-spaced triplet structure, with a small frequency separation close to the main radial pulsation component. This separation corresponds to the Blazhko frequency. Only a small fraction of the observed triplets shows non-equidistant frequency spacing. No convincing evidence of an unambiguous quintuplet structure has been found around the main pulsation component. The vicinity of the side peak(s) to the main peak excludes the possibility of another radial mode being excited. If a triplet structure is observed, the higher frequency side peaks usually (in 75% of the cases) have the larger amplitudes. There could be a continuous transition between the variables showing an equidistant triplet and those displaying only a close doublet, suggesting that both features are the result of the same phenomenon [7]. From previous studies, no direct connection seemed to exist between the pulsation and the Blazhko periods, though recent investigations [21] indicate that modulation with short periods only occurs for stars with the shorter pulsation periods.

Period changes are a common feature in RR Lyrae stars, and also occur in Blazhko stars [2,9]. The observed period variability is too fast to be of evolutionary nature [22]. Its origin is currently unknown, though Stothers (2006) recently proposed an explanation through convective turbulence [23]. Coincident changes in the primary and Blazhko periods have been reported for some Blazhko variables (e.g. [23]). For some stars, two modulation periods have been detected (e.g., XZ Cyg [24], and UZ Uma [25]). Some field Blazhko stars are reported to display, besides their Blazhko cycles, also very long cycles, of the order of years [4].

All RR Lyrae stars, especially of type RRab, undergo large radial motions with high velocities, which make their atmospheres rather tumultuous. At distinct phases in the pulsation cycle, the atmospheres are known to be affected by shock waves, resulting in the broadening and even doubling of certain absorption lines, a peculiarity extensively studied by, e.g. [26,27]. The phase lag between the radial velocities derived from different spectral lines, the so-called Van Hoof

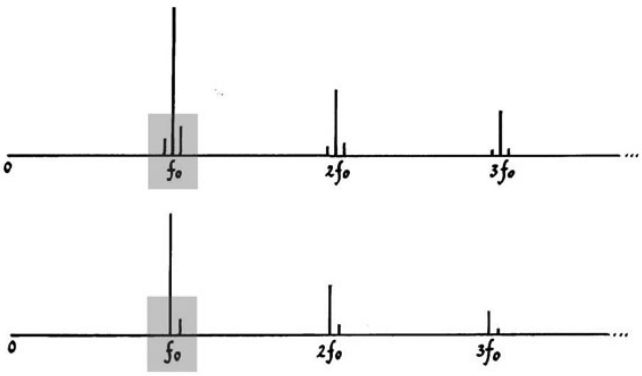

Figure 2. In the frequency spectra of Blazhko stars an equidistant triplet structure or a doublet structure is observed at the main (radial) frequency and ist harmonics. The spacing is exacly equal to the Blazhko frequency.

effect, is interpreted as the time propagation of the pulsation wave through the atmosphere [28]. The above-mentioned phenomena show variable behavior over the Blazhko cycle [14,15], and their spectroscopic study can bring forth clues about the origin of the modulation.

3. Explanations for the Blazhko effect in RR Lyrae stars

Different mechanisms have been proposed to explain the phenomenon, such as resonance effects, nonadiabatic effects, magnetic effects, tidal effects in binary systems, and mode mixing. Evidence of any binary motion has only been found for 2 RR Lyrae stars (Ar Her, TU UMa). It seems that models for the Blazhko effect using only radial mode interactions have failed. For decades, the most plausible hypotheses to explain this phenomenon focused on two types of models, both involving nonradial pulsation components. Recently an alternative scenario was proposed to explain the Blazhko effect [23], which involves a variable turbulent convection due to transient magnetic fields. A schematic overview of the various models for the Blazhko effect is given in Table 1.

- The resonance models are based on a (nonlinear) resonance between the radial fundamental mode and a nonradial mode. In these models the dipole modes $\ell = 1$ in the vicinity of the radial mode have the highest probability to be nonlinearly excited [29-32]. Dziembowski & Mizerski (2004) showed that energy transfer from the radial to the nonradial mode would be needed [32].
- The oblique magnetic models, like the simple oblique pulsator model for roAp stars [33], suppose that Blazhko stars have a magnetic field inclined to the stellar rotation axis [34,35]. The main radial mode is deformed by the magnetic field to have an additional quadrupole component $\ell = 2$, for which the symmetry axis coincides with the magnetic axis. A magnetic field of the order of 1 kG is needed in this model for the amplitude modulation to be observable [35]. So far, magnetic field measurements of RR Lyr itself have yielded controversial results [36-39]. Chadid et al. (2004) [39] most recently reported on spectropolarimetric observations implying no strong magnetic field in the star. RR Lyrae stars might have a magnetic field that is buried deeply and relatively weak at the surface. A straightforward detection of magnetic fields in Blazhko stars is hampered by their relative faintness.

In both the resonance and the magnetic models the observed modulation of the light curve is a consequence of rotation, and hence it is - directly or indirectly - linked to the rotation period. Peterson et al. (1996) [40] measured the line-widths via cross-correlation for 27 RR Lyrae stars and obtained an upper limit for the projected rotational velocity . The observed modulation periods (tens to hundreds of days) could be consistent with the stars rotation period.

Table 1. Schematic overview of the models to explain the Blazhko effect.

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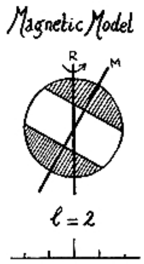
<td></td>
<td>The radial mode is deformed by the magnetic field -> additional ℓ=2 component with symmetry axis coinciding with the magnetic axis.

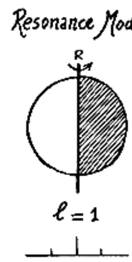
The star's rotation causes the observed amplitude modulation.

A quintuplet structure is predicted in the frequency spectrum, but it may look like a triplet!

1kG field needed according to the models, measurements by Babcock (1958) and Romanov et al. (1994) are controversial, and contradicted by Preston (1967) and Chadid et al. (2004)</td>
<td>A resonance between radial modes can be excluded given the observed frequencies.

Nonlinear resonance between the radial mode and a nonradial mode of low ℓ.

ℓ=1 modes are most probably excited → rotationally split m=±1 modes.

A triplet structure is predicted in the frequency spectrum.</td>
<td></td>
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<td colspan="4">Alternative models not requiring nonradial modes, e.g.,

Stothers (2006)
turbulent convection inside the hyd rogen and helium ionization zones
becomes cyclically weakened and strengthened
due to the presence of a transient magnetic field

tidal effects, companion?, ...</td>
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<td colspan="4">Remaining questions:

Why do we observe modulation components of unequal amplitudes?

Why do RRc stars show a significantly lower incidence rate of the Blazhko effect ?

How to explain deviations from strict amplitude/phase modulation?

How to explain different incidence rates in different populations (LMC,GB)? Role of metallicity?

Role of convective turbulence?

...</td>
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However, angular momentum considerations make it difficult to explain the nontrivial changes in the Blazhko period which amount up to 2% in some stars (e.g. [3,24]).

Many of the observed features cannot be explained with the above-mentioned models (see also Table 1). Finally, convective turbulence may play a role in driving/quenching the Blazhko effect. This is precisely what is addressed in a new scenario for the Blazhko effect, recently published by Stothers (2006). In this model, turbulent convection inside the hydrogen and helium ionization zones becomes cyclically strengthened and weakened due to the presence of a transient magnetic field. A magnetic field can be slowly built up by the turbulent or rotational dynamo mechanism. Subsequent decay of the field leads to a slow cycle of varying turbulent convection, which can be connected with the Blazhko cycle. In Stothers' (2006) [23] model, the observed changes in the pulsation amplitude are not caused by a varying observers aspect angle. Simple radial pulsation in a single mode is sufficient. Irregularity can be explained by the stochasticity of the proposed modulating mechanism. Theoretical models yielding testable predictions are highly desired. This scenario also makes some predictions concerning the period change over the Blazhko cycle, which can be tested with data.

4. Some vital findings over the past decade - To be radial or not to be radial

Close peaks in the oscillation spectra of Blazhko stars may be an indication for the presence of nonradial modes, but are not a definite proof. Over the past decade the first steps were made in the spectroscopic study of the Blazhko effect. From a study of high-resolution spectra of the prototype RR Lyr it was found that the line profile variations depend on the Blazhko phase [16]. Subsequent analysis also provided evidence for the presence of nonradial modes in the star. For such an analysis, a very good coverage is needed over the pulsation cycle and the Blazhko cycle [17,18,20].

A timeline of findings over the past decade illustrates that there have been many observational findings constraining the validity of the models. These were still mostly based on photometric data, e.g., the accurate photometric data gathered with the 60-cm telescope at Konkoly Observatory (Budapest, Hungary) with emphasis on short-period RR Lyrae stars. Results based on large variable star surveys fine-tune the statistics. Through an analysis of the Fourier coefficients of modulated and non-modulated stars, it was shown by Jurcsik et al. (2002) [41] that the light curves of Blazhko stars are never like those of non-Blazhko stars, thus always distorted. The discovery of Blazhko stars with tiny modulation amplitudes implies that Blazhko stars may be much more common than we presently think they are. Jurcsik et al. (2005) [42] detected, for the first time, a connection between the pulsation and modulation properties of RRLyr stars. Their interpretation of the detected tendency is directly linking the Blazhko period with the surface rotation period, which is a plus for the magnetic models. On the other hand, the discovery of changing Blazhko periods and multiple Blazhko periods (see Section 2) seem to challenge the models. RR Lyrae stars are also observed to radically change their pulsation behavior, such as V79 in M3 [43]. In RRd star AQ Leo additional pulsation comonents were detected which might also be nonradial [44]. From the application of a photometric method to determine the metallicity of RRab stars, Smolec (2005) [45] concluded that the different metallicities of the Galactic bulge and the LMC, cannot explain the observed incidence rates.

From the theoretical side, most of the presently cited plausible models were published (in their latest versions) over the past decade. But whereas the resonance models have known a steady refinement over the years [29-32], the magnetic model has remained in its original form [35]. Dziembowski & Mizerski (2004) [32] published a scenario for maintaining nonradial modes in RR Lyrae stars, a resonance model in which the nonradial mode is fed by the radial one. However, scenarios that can do without nonradial modes are worth exploring [32]. In any case, the models are lagging behind in the explanation of the Blazhko effect.

Therefore, large contributions to the understanding of the Blazhko effect can be made by exploring and improving the models, i.e., hydrodynamical pulsation models of RR Lyrae stars (e.g. [46,26], as well as the models for the Blazhko modulation, to obtain a general better agreement with the observations. On the other hand, for modern telescopes and instruments precise high-resolution spectroscopic data of Blazhko stars have come within reach.

5. The Blazhko Project

The Blazhko Project is a larger international collaboration, set up to join efforts in obtaining a better understanding of the Blazhko phenomenon in RR Lyrae stars [47]. The aim of the project is to combine spectroscopic and photometric data from a sample of well-selected Blazhko and non-Blazhko stars, in order to reveal decisive information on the physical mechanism responsible for the modulation. The project was founded (and funded) in Vienna and started its activities in 2004. A dedicated website gives the background as well as the present status of investigations: **http://www.univie.ac.at/tops/blazhko/**. The starting point for improving the modelling is an extensive data set of a limited sample of field RR Lyr Blazhko stars in both hemispheres. Important is the inclusion of a few selected non-Blazhko RR Lyr stars in the target list of which similar data are being gained, to be compared with the Blazhko stars.

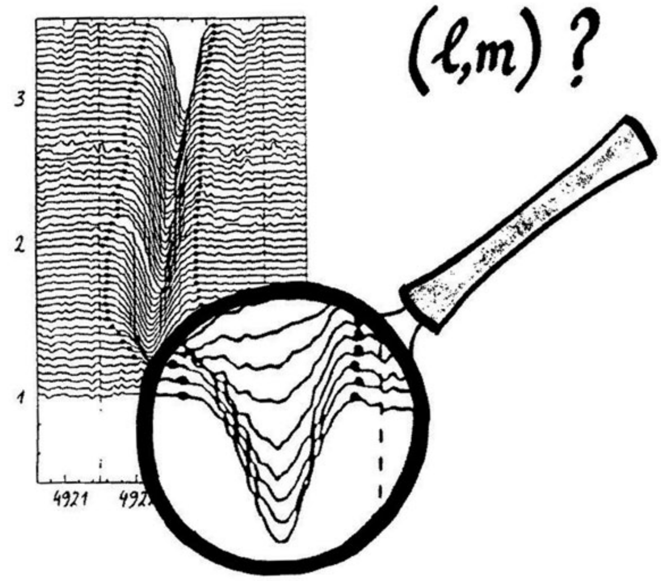

Figure 3. Spectroscopic mode identification: to find out the geometry of the small nonradial mode the dominant radial mode has to be filtered out.

The data set contains high-resolution ($R > 40000$), high-S/N ($S/N > 100$) spectroscopic data evenly spread over the Blazhko cycle for the target stars. A few very detailed snapshots ($S/N > 200$) are obtained with telescopes in the 8-m class (HET, VLT), and will help to distinguish between different nonradial modes. Additional radial velocities over a longer time base can be obtained with smaller telescopes, and provide necessary information to interpret the line profile variations. Finally and importantly, photometric data gathered over a time base of at least a year, are needed to ensure the required frequency resolution. For the photometry, small telescopes are ideally suited. Therefore, the collaboration also involves amateur astronomers and also makes use of robotic facilities in both hemispheres.

For the interpretation of the data we start from the available spectroscopic identification methods, which need adaptation for nonlinearly pulsating stars. Also magnetic field observations of more and fainter RR Lyrae stars have come within reach and will be attempted in the near future.

This project's aims are complementary to the already existing investigations focused on the Blazhko effect, particularly because of its emphasis on spectroscopy.

6. Finally: why bother?

The Blazhko effect is one of the last unexplained mysteries in classical pulsators and for stellar pulsation theory in general. Solving the century-old puzzle will not only enlarge our understanding of the structure of RR Lyrae stars, better pinpointing their exact evolutionary status, but it will also clarify similar phenomena occurring in other types of pulsating stars.

An increased knowledge of the structure and the dynamical and physical properties of the atmosphere of RR Lyrae stars has important astrophysical implications on the theory of stellar structure, pulsation and evolution. Importantly, the presence of the Blazhko effect often renders the interpretation of the observed pulsation properties of stellar systems, especially in terms of the Bailey (period-amplitude) diagram and Fourier decomposition parameters, very uncertain [48]. Moreover, RR Lyrae stars play a crucial role in the definition of the cosmic distance scale. Hence it is important to investigate whether the light curve modulation poses any problem at all in the calibration of the distance scale.

The study of the Blazhko effect has potential benefits for other aspects of multiperiodic variable star research. Similar effect so beating are found in other pulsating stars such as a few

Cepheids, W Vir stars, and pulsating red giants with long secondary periods, δ Scuti, and β Cephei stars ([49] and references therein).

Getting to the bottom of the Blazhko mystery will provide us with new understanding of convection, magnetic activity and atmospheric hydrodynamics in giant stars.

Acknowledgments

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